APPENDIX

The ICI Polyurethanes Book

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Published jointly by

ICI Polyurethanes

and

JOHN WILEY & SONS
Chichester · New York · Brisbane · Toronto · Singapore

Library of Congress Cataloguing in Publication Data:

Woods, George

The ICI Polyurethanes Book
Bibliography: p
Includes index

1. Polyurethanes
I. Imperial Chemical Industries PLC II. Title
TP1180.P8W66 1987 668.4'239 86-28590
ISBN 0 471 91426 6

British Library Cataloguing in Publication Data

Woods, George

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1. Polyurethanes
I. Title.
668.4'239 TP1180.P8
ISBN 0 471 91426 6

Printed and bound in The Netherlands.

Such reticulated foams are very efficient filters for the removal of dust and fibres from air and other gases. They allow high flow rates combined with low pressure gradients and, therefore, minimum energy consumption. Many methods of reticulation have been used, including chemical hydrolysis and the use of an explosion flame front to melt the membranes.

Impregnation Impregnation of low density flexible foam is a process that includes the coloration of foam by dyeing and by coating with pigments in a binder or surface coating, the application of anti-fungal coatings, water resistant coatings and ion-exchange resins for special applications, but the most important treatment is impregnation with flame-retardants, especially with aluminium hydroxide. Foams are impregnated with up to 300% by weight of aluminium hydroxide usually with a synthetic latex binder, to meet the highest flame resistance requirements in upholstery for public and institutional use.

Moulded low density flexible foam

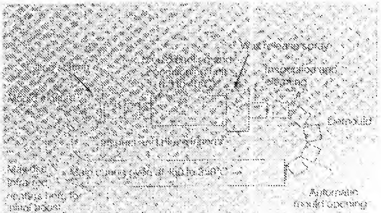
Nearly 20% of low density flexible polyurethane foam is produced as finished products by moulding in closed moulds. Moulded foam is used for vehicle seating and interior trim, including sound absorbing trim, in furniture upholstery and bedding and in packaging. Two types of process are used: the hot moulding process, which has been established for over twenty years, and the more recent cold-cure moulding processes. Hot moulded foam is made by the reaction of TDI with polyether triols similar to those used in slabstock manufacture. External heat is applied to the mould after filling in order to obtain sufficient surface cure of the foam moulding to allow its early release from the mould. Cold-cure moulded foams are based on polyether triols with equivalent weights in the range from about 1,500 to 2,000 and isocyanate mixtures with an average functionality greater than two. Suitable isocyanates include special MDI compositions, mixtures of polymeric MDI and TDI, and TDI that has been modified to increase its effective functionality. The reactivity of the isocyanates in conjunction with suitable catalysts gives a sufficiently fast cure of the foam surface in contact with the mould, even at temperatures only slightly above room temperature. Wholly MDI based foams give the fastest cure and mould temperatures are generally lower than those for TDI/MDI systems.

Hot moulding Cast aluminium moulds with wall thicknesses of between 6 mm and 8 mm are used for hot moulding, or fabricated sheet metal moulds that are usually made from black steel sheet 1 mm to 2 mm thick. Moulds are usually made in two sections with provision for mechanical opening and closing of the lid. The choice of mould construction will depend on the required life of the mould,

on the number of similar moulds required, and on the dimensional tolerances of the moulded product. Aluminium, having over four times the heat conductivity of steel, is preferred, as it allows the construction of a stiff mould giving the minimum heating cycle and hence the minimum energy consumption. Cast aluminium moulds are also preferable to thin sheet metal moulds because they resist distortion during heat cycling and give a more uniform inner surface temperature during the heat curing stage. Moulds are usually designed to allow about 1% shrinkage of the moulded foam during manufacture but mouldings of complex shape require prototype mould trials to determine the shrinkage accurately and to find the optimum number, size and position of the vent holes that will give a product of the required high quality. It is best for the inner surface of the mould to have a coarse matt or 'scratch-brush' finish that gives good retention of the release agent and helps in obtaining moulded articles with the desired thin, highly-permeable skin.

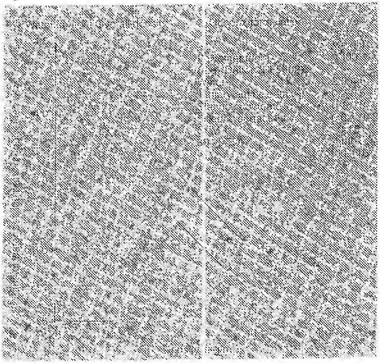
The conventional hot-cure moulding process is based upon TDI. A predetermined amount of the foam reaction mixture is dispensed into moulds conditioned at a temperature of about 40°C. The closed mould is then passed through a curing oven at a temperature of 150° to 250°C, depending on the mould design and the production speed required, to raise the temperature of the inner surface of the mould quickly to about 120°C. This raises the temperature of the surface of the moulded foam to near the exothermic reaction temperature of the interior of the moulding and allows the cushion or other moulded article to be demoulded in 6 to 12 minutes. The hot mould then passes, in succession, to stations for cleaning, application of release agent, cooling, and back to the filling point (figure 1-16).

Figure 1-16 Hot-cure moulding



Hot-cure moulding formulations are based upon specially developed polyether triols, and 80:20 TDI. The foam density and hardness depends basically on the level of water and isocyanate used for blowing, the TDI index, the shape of the mould and the degree of overpacking used, i.e. the amount of foam reaction mixture used compared with the minimum amount required to just fill the mould under the given operating conditions. The effect of water blowing on moulded foam density is shown in figure 8-17 together with a general formulation. All moulded foams show a density gradient from the core to the surface. The difference between the core density and the overall density of a moulded foam cushion is usually between 10% and 20%, but may be higher for complex shapes with a high surface-to-volume ratio. Soft foam mouldings for seat backs and pillows are usually made by reducing the isocyanate index and/or by utilising auxiliary blowing with CFM-11.
The heat cycling of the moulds from about 40°C to an outer surface temperature up to about 140°C is, however, expensive in terms of both energy and time.

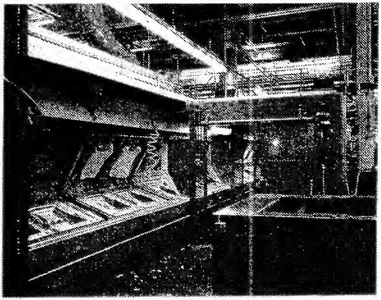
Figure 8-17 Hot-cure moulding: Formulation/Water content/Overall density



Cold-cure moulding This allows moulds to be used at a relatively low and nearly constant temperature, uses much less energy and allows the use of fewer moulds and the use of alternative non-metallic mould constructions.

Cold-cure moulding systems are often specially formulated as two-component systems to meet specific applications required by foam users in the automotive and furniture industries. Typically, such two-component foam systems may be mixed and poured into moulds conditioned at 35 to 60°C, depending on the foam system adopted and on the conductivity of the material used for the mould. TDI-based systems, in general, require the highest mould temperatures whereas all MDI-based foams use mould temperatures from 25 to 45°C. The completed moulding may be demoulded a few minutes after pouring, without the need for application of external heat to complete the cure.
A wide range of machinery is used for cold-cure moulding. The simplest production facilities employ a two-component dispensing machine, with the shot weight controlled by an adjustable timer, and GRP moulds that are manually opened and closed. On the other hand, large numbers of seat cushions for vehicles are made on large oval tracks incorporating devices for automatic mould opening, filling and closing. Microprocessor control of the dispensing machine is usual on modern production lines. It gives more accurate shot weights than electrical sequence timers and is more easily and cheaply adapted to control the weight of foam dispensed into each individual mould. Requirements for smaller rates of production are met by the use of small carousels or by static moulds. The latter are temperature-controlled moulds into which foam reaction mixture is dispensed, usually by a high pressure, self-cleaning, impingement mixing head. A high output cold-cure moulding line is illustrated in figure 4-18.

Figure 4-18 A typical high resilience foam moulding line



Moulds for cold-cure moulding differ from those required for hot-cure in several ways.

- Most cold-cure foam systems give the best moulding performance in 'overpacked' moulds, i.e. when using significantly more foam reaction mixture than the minimum amount required to just fill the mould. In consequence cold-cure moulds need to be designed to withstand up to 0.5 bar internal pressure. Venting of the mould and the sealing of the parting line is more critical than for hot-cure moulding.
  Most cold-cure foam systems give optimum moulding results when moulded under conditions that give a proportion of closed cells in the freshly-made foam. These closed cells are crushed soon after demould in order to avoid permanent deformation of the mouldings caused by cooling and by the diffusion of gas from the closed cells. The overall effect of the difference in the condition of the foam at the end of foam rise, combined with early crushing is that many cold-cure foam mouldings show slightly greater shrinkage from the mould and this must be allowed for in designing the mould.
- The lower operating temperatures and the greatly reduced range of the temperature cycle allow a much greater choice of materials for the construction of moulds for cold-curing foams.
  Non-metallic moulds are frequently used for furniture cushions and have proved very durable. Typical moulds are made from glass-fibre-reinforced epoxy resins, suitably braced to withstand the internal moulding pressure.

Chemicals for cold-cure moulding. The basic materials are polyether resin with a high ratio of primary to secondary hydroxyl groups and with a mean molecular weight from about 4,000 to 6,000. Reinforced polyols, i.e. polymer polyols, PIPA polyols and PHD polyols are also used. The isocyanate component may be a modified TDI, a modified MDI or an MDI/TDI mixture. The moulding cycle ranges from over 10 minutes for some cold-curing MDI/TDI based systems to less than 4 minutes for systems based on specially-developed MDI variants. Cold-cure moulding systems based upon MDI variants are becoming popular. They give short moulding cycles without high consumption of energy and the product is a foam with a soft permeable skin that handles like rubber latex foam. MDI-based foam systems require relatively low concentrations of reinforced polyol to produce high load-bearing foams. There are also environmental benefits resulting from the relatively low vapour pressure of modified MDI compared with that of TDI. One range of foam systems based on MDI variants is designed to make furniture cushioning with indentation hardnesses ranging from 90 N to 350 N and with core densities of between 35 to 70 kg/m^3. Systems are also available to meet the specifications for

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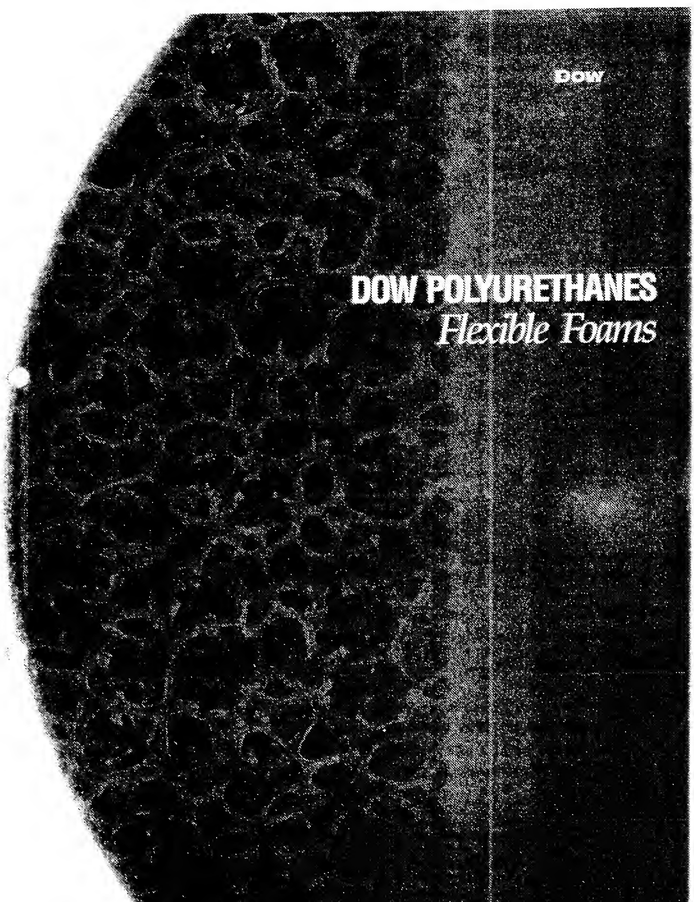

Flexible Polyurethane Foams

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Second Edition Published 1997

Printed in the United States of America

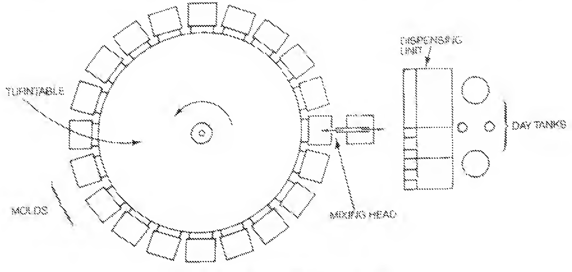

Figure 5.18 Carousel Molding Line

strong clamps. Since these foams are prone to collapse with untimely pressure relief, venting must be carefully controlled.

A proper initial mold temperature is critical for the production of cosmetically acceptable foam surface skins. For hot-molded foams, temperatures around 100°F (37°C) are preferred. If the mold is cooler than about 77°F (25°C), an undesirable densified layer of skin will form. When the mold gets too hot, the skin becomes exceedingly thin and fragile. HR foams vary widely in chemistry, with some systems requiring only ambient temperature molds, while other systems perform best with initial mold temperatures in the range of 140-160°F (60-71°C). At excessive temperatures, HR foams exhibit cosmetic surface and subsurface defects. With either chemistry, the molds should be sized to allow for about 2% shrinkage of the final molded part.

Most semiflexible foam processes run best when the mold temperature is carefully controlled in the range of 85-110°F (29-43°C). Beyond these limits, foam flowability and internal mold pressure problems occur.

Mold-Releases

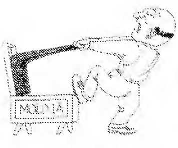

Figure 5.19 The Need for Mold-Release Agents

Figure 5.19 emphasizes that without a purposely applied mold-release, removal of a foam part from a mold would be very difficult. Polyurethanes make excellent adhesives. The principal mold-release agents used are commercial blends of various natural and synthetic waxes. The exact composition is chosen so that the melting point of the wax is slightly below the stripping temperature of a given foam line. The release agent is thus a solid during the pour and gelation parts of the cycle. As the mold approaches the demolding temperature, the release agent becomes liquid and allows the foam to be easily stripped from the mold. This type of hot wax mixture gives optimum release properties, but must be renewed after each molding. In

some cases it is desirable to use a film-forming mold release that can go with the part in order to serve as a protective or decorative coating for the finished product (e.g., toys).

Mold-releases can be characterized as either water or solvent-based. Detailed review articles can be found at References 5.136-5.142. Recent developments in water-based systems are reported in References 5.143-5.153.

Hot-Cure Molding

A typical layout for a hot-cure molding line is shown in Figure 5.20. The molding line is in essence a drag-chain conveyor moving molds from one operating station to another.[5.154] The process begins with the molds entering the preheat oven, where they are typically heated to 104-122°F (40-43°C); epoxy molds are heated slightly higher.

After exiting the preheat oven, the molds proceed via conveyor to the pour station. An exhaust system with its inlet near the pour conveyor removes vapors from the area. The residence time at the pour station is sufficient to charge the molds and allow the foam to cream. The reaction mixture can be dispensed into the molds as a puddle or by strip pouring as required for optimum mold filling characteristics. The molds are normally closed automatically as they are conveyed to the radiant oven. The foam dispensing machine may feed one or two mixing heads suspended from booms, robots or other pour bridges. The polyol and isocyanate are transferred from bulk storage to day tanks, which are usually an integral part of the dispensing unit. Water, catalyst and surfactant are normally stored in separate day tanks. Precision pumps feed the components to the mixing head, and the components are normally recirculated between pours. The mixing head may be either the low or high-pressure type.

In the radiant section of the oven, the molds are heated to an internal surface temperature of about 250°F (121°C). The remainder of the curing oven is heated with hot air. At the end of curing, the molds are opened automatically and the foam is removed. The molds are then cleaned, sprayed with fresh mold-release and fitted with the required inserts and wires. From there the molds travel through a cooling and conditioning station to bring them back to the proper pour temperature. The stripping, waxing and cooling areas are also under ventilation. A typical molding cycle for a hot-cure line is given in Table 5.4.

Table 5.4 Hot-Cure Molding Cycle

Process Steps	Time(Minutes)
Preheat	3.0
Pour	0.5
Cure	15.0
Demold and Wax	6.0
Cool	5.5
Total	30.0

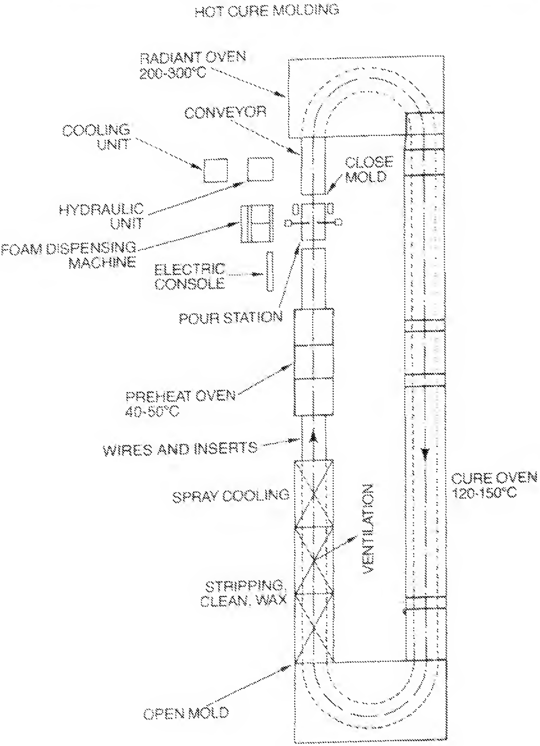

Figure 5.20 Typical Hot-Cure Molding Line

HR Molding

Foam formulations that cure at lower temperatures are the basis of most HR-foam processes. Various formulations exist that require no or greatly reduced heating cycles. With many systems, curing ovens are not needed and low mold temperatures allow the molds to be lined with ABS, PVC or upholstered skins, thus allowing the production of finished parts in a single process. The cycle time of most HR cold-cure moldings is approximately half that of hot-cure. This results in shorter, simpler conveyor lines and reduced equipment costs. Figure 5.21 illustrates a typical racetrack-style molding line for HR seating foam. More complex designs are also used.[5.14]

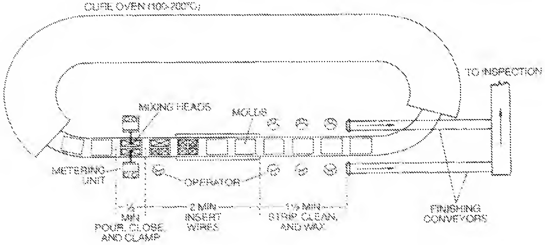

Figure 5.21 Racetrack-Style Molding Line

Depending on the foam system, the formulated ingredients are mixed and dispensed into waxed molds conditioned to a temperature in the range of 120-160°F (49-71°C). The molds proceed along any of various designs of conveyor systems, which are usually equipped for automatic closing and locking of the lids. In the case where auxiliary heat input is desired, as in low-density seating foam, the mold then enters a curing oven of sufficient temperature to bring the internal mold surface temperature up to the range of 170-200°F (77-93°C). After a mold residence time of 3 to 10-minutes, the mold is opened and the part is removed, either mechanically or by hand. The mold then proceeds through cleaning, waxing and other preparation stations before returning to the pour station. In contrast to open-celled hot-molded foam, most HR foams contain closed-cells that must be mechanically opened by means of a press, air injection, roller crushers, or by the vacuum crushing technique.

Specialty Molded Foams

These foams include the semiflexible, semirigid and integral-skin types of foams more fully defined in Chapter 12. In general, semiflexible molded

foams are used in instrument panels, arm rests, console covers, door panels and other foam parts found in automobile interior.

In a typical semiflexible foam molding operation, a vinyl skin would be placed in the bottom of a waxed, temperature controlled, cure mold. Then the mold is fitted with a structural insert and foam is then dispensed into the mold in either a open or closed-mold process. The foam fills the cavity between the vinyl and the insert and provides both adhesion and cushioning properties. After curing, the composite part is demolded and subjected to additional trim and fabrication steps before shipment to the final customer.

CARPET BACKING

In the manufacture of tufted carpet, an adhesive backing is required to anchor the tufts. This backing is most commonly applied in two separate coatings. The first, known as the precoat, is driven into the back-stitch of the carpet to achieve penetration of the yarn bundles, with encapsulation of each fiber as the optimal target. The second coating is known as the adhesive or laminate coat. The purpose of the laminate coat is to adhere a secondary fabric, most commonly a woven polypropylene material, to the body of the carpet. Since the two coatings serve different purposes, it should not be a surprise that the formulations and polymers are different as well. A lower volume backing system, known as unitary, incorporates increased weights of precoat and a second coating, but does not utilize a secondary fabric on the outer surface. Unitary products are typically targeted at higher performance applications and command a premium price. It should be noted however, that unitary carpets are known to have a higher level of field installation problems than laminate products.

The most popular carpet backing systems are based on Styrene-Butadiene (SB) latexes, which give good tuft-lock at low cost. Another backing approach is the application of a resilient foam backing over the anchor coat. Foamed materials used for this backing are PVC plastisols, polyurethanes, EVA and latex. Although polyurethane raw materials are more expensive than latex, advantages in processing physical properties and durability cause polyurethanes to be the foam of choice.[156] A processing advantage is lower energy consumption due to lower operating temperatures of the curing ovens. In latex foams, large amounts of water must be evaporated; this need is not present in polyurethane foams.

Significant research has been done to evaluate the field performance of THE ENHANCER polyurethane attached cushion. The attached cushion improves appearance retention of the carpet by reducing the energy absorbed by the carpet face during use. Studies have shown improvements of up to double the appearance rating when comparing the same carpet face with and without cushion at equivalent traffic counts. This translates into a longer life cycle for carpets incorporating an attached cushion, compensating for the additional cost of the backing. An obvious secondary advantage to attached cushion is improved walking comfort. Extensive studies on various aspects of comfort and comfort retention reveal important differences between cushioned and non-cushioned carpet, and between comfort imparted by high